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(71) Applicant: CALIENT NETWORKS, INC. [US/US]; 5853 Rue Ferrari, San Jose, CA 95138-1857 (US).

(72) Inventor: CHONG, John, Matthew; 1535 Loma Street, Santa Barbara, CA 93103 (US).

(74) Agents: MALLIE, Michael, J. et al.; Blakely, Sokoloff, Taylor & Zafman LLP, 12400 Wilshire Boulevard, 7th floor, Los Angeles, CA 90025 (US).

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(54) Title: BULK SILICON STRUCTURES WITH THIN FILM FLEXIBLE ELEMENTS

(57) Abstract: A method for forming a suspend structure with thin film flexible elements is disclosed. In one embodiment, the method etches a trench in a bulk substrate around to be released components. The trench is filled with sacrificial material. The surface of the sacrificial material is planarized. Thin film hinge material is patterned and etched on the surface of the sacrificial material. The bulk substrate is then etched from the backside to pre-release the sacrificial material. The sacrificial material is etched to remove the sacrificial material, thus forming a suspended structure with thin film hinges.

BULK SILICON STRUCTURES WITH THIN FILM FLEXIBLE ELEMENTS

FIELD OF INVENTION

The present invention pertains to the field of micro-electro-mechanical-system (MEMS) devices. More particularly, the present invention relates to a MEMS mirror device.

BACKGROUND OF THE INVENTION

A MEMS device is a micro-sized mechanical structure having electrical circuitry fabricated, for example, by using conventional integrated circuit (IC) fabrication methods. One type of MEMS device is a microscopic gimbaled mirror device. A gimbaled mirror device includes a mirror component, which is suspended off a substrate, and is able to pivot about two axes. Motion is caused by electrostatic actuation. Electrostatic actuation creates an electric field that causes the mirror component to pivot. By allowing the mirror component to pivot in two axes, the mirror component is capable of having an angular range of motion in which the mirror component can redirect light beams to varying positions across a two-dimensional surface.

A prior method for fabricating the mirror component is by using a purely thin film process to fabricate the mirror and the hinge. The thin film process can fabricate a hinge that has well defined dimensions, thus enabling large and controllable deflections of the mirror. However, the mirror produced by the thin film process suffers from poor quality. For example, a thin film mirror has a rough surface. Also, the thin film mirror does not maintain a flat surface. Instead, the mirror becomes deformed and develops a curvature because the thin film is not capable of resisting the strains placed on the large surface of the mirror.

Another prior method for fabricating the mirror and hinge is to use purely bulk film method. The bulk process creates a high quality mirror having a smooth surface. Also, the strength of the bulk material can maintain the flat surface of the mirror, so that the mirror does not become deformed or curved. However, the bulk process cannot define the dimensions of the hinge very well. As a result, the hinge cannot produce controllable, well defined mirror deflections.

SUMMARY OF THE INVENTION

A method for forming a bulk mirror with thin film hinges is disclosed. In one embodiment, the method etches a trench in a bulk substrate around to be released components. The trench is filled with sacrificial material. The surface of the sacrificial material is planarized. Thin film hinge material is patterned and etched on the surface of the sacrificial material. The bulk substrate is then etched from the backside to pre-release the mirror. The sacrificial material is etched to remove the sacrificial material, thus forming a bulk mirror with thin film hinges.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of example and not limitation in the figures of the accompanying drawings, in which like references indicate similar elements, and in which:

Figure 1 is an illustration of an embodiment of an optical switch having a mirror device that includes a thin film hinge and a bulk mirror.

Figure 2 is a top view of MEMS mirror device having a thin film hinge and a bulk mirror without electrodes and a wiring pattern.

Figure 3 is a top view of MEMS mirror device having a thin film hinge and a bulk mirror with electrodes and a wiring pattern.

Figures 4A and 4B are a cross-sectional side views of one embodiment along the line A-A' such as that shown in Figure 3.

Figures 5A through 5G are cross-sectional views illustrating process steps of a method for fabricating a mirror device having a thin film hinge and a bulk mirror.

DETAILED DESCRIPTION

A method for forming a bulk mirror with thin film hinges is disclosed. In one embodiment, the method etches a trench in a bulk substrate around released components. The trench is filled with sacrificial material. Optionally the surface of the sacrificial material is planarized. Thin film hinge material is patterned and etched on the surface of the sacrificial material. The bulk substrate is then etched from the backside to pre-release the sacrificial material. The sacrificial material is etched to remove the sacrificial material, thus forming a bulk mirror with thin film hinges.

The combined bulk etching and thin film process provides several advantages. First, the bulk mirror has a high quality mirror surface that is flat, smooth, and has no intrinsic stress. Second, the thin film hinge enables a great degree of control over the hinge dimensions. Also, the choice of the thin film hinge materials can vary based on the desired performance of the hinge. For example, if the hinges need to be under tension, an appropriate material to provide this property can be selected. Alternatively, if the hinge needs to come to rest quickly after moving from point A to point B, a material with good damping properties, such as plastic, can be selected. The hinge dimensions can thus be small enough to provide large, controllable deflections of the mirror.

Furthermore, the topside metal surface can be easily patterned on the planar surface of the bulk substrate.. This allows for the metal to be located only on the mirror if desired.

Figure 1 is an illustration of an exemplary optical switching system 10 including bulk mirror with thin film hinges. For example, optical switching system 10 may represent a 3-dimensional optical switching system. A 3-dimensional optical switching system allows for optical coupling between input fibers and output fibers in different planes using lens arrays and mirror arrays. The lens arrays and mirror arrays provide proper angle and position of light beams traveling from input fibers to output fibers. That is, a light beam must leave and enter a fiber in a direct path. Thus, using the optical switch shown in Figure 1, any optical input can be connected to any optical output through the mirror arrays 20A and 20B, which contain mirrors that can be rotated along two axes.

Referring to Figure 1, optical switching system 10 includes input fiber array 40, input lens array 30A, input MEMS movable mirror array 20A, output MEMS movable mirror array 20B, output lens array 30B, and output fiber array 60.

Input fiber array 40 provides a plurality of optical fibers 50 for transmitting light to input lens array 30A. Input lens array 30A includes a plurality of optical lenses, which are used to collimate and focus beams of light from input fiber array 40 to individual MEMS mirror devices on MEMS input movable mirror array 20A. MEMS input mirror array 20A includes a plurality of electrically addressable MEMS mirror devices 100. The mirror device 100 are bulk mirrors with thin film hinges.

MEMS mirror device 100 may be a gimbaled mirror device having a rectangular shape. Alternatively, MEMS mirror device 100 may be a

gimbaled mirror device having an arbitrary shape, such as an elliptical or circular shape for example. The plurality of MEMS mirror devices 100 for MEMS input movable input movable mirror array 20A can pivot a mirror component to redirect or reflect light to varying MEMS mirror devices on second MEMS mirror array 20B. MEMS output movable mirror array 20B also includes a plurality of MEMS mirror devices such as MEMS mirror device 100, which are used to redirect and reflect light beams to varying lenses on output lens array 30B. Output lens array 30B collimates and focuses beams of light from output mirror array 20B to individual output fibers 70 of output fiber array 60.

Optical switching system 100 allows light beams from any input fiber 50 of input fiber array 40 to be redirected to any output fiber 70 of output fiber array 60. For example, a light beam following the path "A" is outputted from one input fiber and is redirected using MEMS mirror arrays 20A and 20B to a different output fiber. The MEMS mirror arrays may also be used in scanning systems, printing systems, display systems, and other systems that require redirecting beams of light.

Figure 2 is top view of one embodiment, of a MEMS mirror device, having a bulk and thin film hinges, without electrodes and a wiring pattern illustrating a first mirror device 9A and a second mirror device 9B having a support structure 5, thin film hinge pattern 6, and bulk mirror pattern 7. Bulk mirror pattern 7 may include a center mirror component 7a and frame pattern 7b. Center mirror component 7a is capable of having an angular range of motion with respect to an axis. Frame pattern 7b provides support for center mirror component 7a.

Figure 3 is a complete top view of one embodiment of a MEMS mirror device such as that shown in Figure 2 further illustrating electrodes 4 and wiring pattern 2 for the first mirror device 9A and

second mirror device 9B. A MEMS mirror device includes a substrate 1 having wiring pattern 2 formed thereon. Electrodes 4 are formed such that electrodes are coupled with wiring pattern 2. An insulation layer 3 is formed to provide insulation for wiring pattern 2 and electrodes 4.

The center mirror component 7a is formed such that it is disposed above electrodes 4. Center mirror component 7a includes a reflective surface to reflect beams of light. Electrodes 4 are located below at opposing edges of center mirror component 7a. Center mirror component 7a may also be connected with a ground line (not shown) in substrate 1 for electrical shielding purposes. Electrodes 4 are coupled with a respective wiring pattern 2 located on substrate 1. Alternatively, a ground line may be disposed between electrodes 4 and wiring pattern 2 for purposes of electrical shielding.

Center mirror component 7a may move about an axis to have an angular range of motion caused by electrostatic actuation from electrodes 4. Electrostatic actuation is caused by a voltage being applied to electrodes 4 through wiring pattern 2. A voltage applied to electrodes 4 creates an electric field between, for example, electrodes 4 and center mirror component 7a. The electric field may be created near the edges of center mirror component 7a. The electric field causes center mirror component 7a to have an angular range of motion with respect to an axis such as, for example, an axis parallel to hinge pattern 6.

Figures 4A and **4B** are a cross sectional side views showing the structure of one embodiment of a MEMS mirror device having a bulk mirror and thin film hinges taken along the line A-A' such as that shown in **Figure 3**. Support structure 5 may be made from the same wafer materials as bulk mirror. Support structure 5 may include a post structure to provide support for layers formed thereon or attached

therewith. Support structure 5 may define a honeycombed shape. Support structure 5 may also define holes such that the holes are centered approximately below the center mirror component. Support structure 5 provides support for thin film hinge pattern 6 and bulk mirror pattern 7.

Bulk mirror pattern 7 includes a center mirror component 7a and frame pattern 7b. Thin film hinge pattern 6 is attached with mirror pattern 7 and support structure 5. Thin film hinge pattern 6 may be a thin and flexible material. Hinge pattern 6 provides support for bulk mirror pattern 7. Frame pattern 7b provides support for center mirror component 7a.

Figures 5A through 5F are cross-sectional views illustrating process steps of a method for fabricating the MEMS mirror device having a bulk mirror and a thin film hinge. For simplicity, the gimbal is not shown.

Referring to **Figure 5A**, a trench 610 is etched into substrate 600. Substrate 600 is a bulk material (e.g., a silicon wafer) which is formed from a single crystal. Thus, the surface of substrate 600 is flat and has no intrinsic strains. The trench 610 may be etched into bulk substrate 600 using a vertical anistropic etch. Referring to **Figure 5B**, the trench 610 is one continuous trench surrounding an area 620 that will become the mirror.

Referring to **Figure 5C**, the trench 610 is filled with a sacrificial material 630. A dielectric material such as silicon dioxide (S_1O_2), silicon nitride (Si_xN_y), or silicon oxynitride ($Si_xO_yN_z$) may be used as sacrificial material 630 to fill trench 610. The material 630 may be inserted into trench 610 by a spin on glass process, where liquid glass is poured into trench 610, and substrate 600 is spun to remove any excess material 630. It may be formed through diffusion process such as thermal oxidation of

Silicon. Alternatively, it can be formed by any other deposition process such as TEOS or CVD. The surface 640 of substrate 600 and material 630 may then be planarized to remove any dips in the surface of the substrate and the sacrificial material. The surface may be planarized by polishing, for example.

Referring to Figure 5D, thin film hinge material 650 is deposited and patterned on surface 640 of sacrificial material 630. The thin film hinge material can be a polysilicon layer that is selectively patterned and etched to form a hinge pattern. Alternatively, a polymer layer, oxide layer, nitride layer, silicon nitride Si_xN_y layer, silicon dioxide SiO_z layer, or silicon oxynitride SiO_yN_z layer may be used to selectively pattern and etch the thin film hinge or any other appropriate material or combination of materials can be used. The thin film hinge pattern 650 is formed to be thin and flexible.

Referring to Figure 5E, at least one layer having light reflective properties is formed on exposed surface area of region 620 of bulk substrate 600. For example, a material layer having light reflection properties may be formed on area 620 and selectively patterned and etched to form mirror pattern 660. The metal layer or maybe a gold (Au) metal layer, aluminum (Al) metal layer, a copper (Cu) metal layer or a dielectric stack. The metal layer 660 is supported by bulk substrate 600. Because bulk substrate 600 is formed from a single crystal, bulk material 600 has no internal stresses and will maintain a flat surface, so that mirror 660 will remain flat and smooth.

Referring to Figure 5F, the backside of substrate 600 is etched to remove excess bulk material from substrate 600 to pre-release the region 620 of the bulk material.

Referring to Figure 5G, the sacrificial material 630 removed by an etching process. For example, substrate 600 may be placed in a hydro-fluorine (HF) acid etching solution to remove sacrificial material 630 from substrate 600. In this case the choice of materials for the hinge and mirror surface need to be resisted to be the protected from the etching.

In the foregoing specification, the invention has been described with reference to specific exemplary embodiments thereof. It will, however, be evident that various modifications and changes may be made thereto without departing from the broader spirit and scope of the invention as set for in the appended claims. The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense.

CLAIMS

What is claimed is:

1. An article of manufacture comprising:

a frame;

a bulk structure; and

thin film hinges attached to the frame and the bulk structure, so that the bulk structure is suspended.

2. The article of claim 1 wherein the bulk structure is silicon.

3. The article of claim 1 wherein the thin film hinges are a layer selected from the group comprising:

polysilicon, polyoxide, nitride, silicon nitride, silicon dioxide, or silicon oxynitride.

4. The article of claim 1, further comprising a mirror located on the bulk structure.

5. The article of claim 4, wherein the mirror is a layer selected from the group comprising gold, aluminum, copper, or dielectric stack.

6. An optical switch comprising:

an input array of input optical fibers to input light beams into the switch;

a lens array to collimate the light beams;

an output array of output optical fibers to output light beams from the switch;

a mirror array having a plurality of mirror devices to optically connect one input optical fiber to one output optical fiber;

each mirror device including a frame, a bulk structure, and thin film hinges attached to the frame and the bulk structure, so that the bulk structure is suspended.

7. The switch of claim 6 wherein the bulk structure is silicon.

8. The switch of claim 6 wherein the thin film hinges are a layer selected from the group comprising:

polysilicon, polyoxide, nitride, silicon nitride, silicon dioxide, or silicon oxynitride.

9. The switch of claim 6 wherein a mirror located on the bulk structure.

10. The switch of claim 6 wherein the mirror is a layer selected from the group comprising gold, aluminum, copper, or dielectric stack.

11. A process for fabricating a suspended bulk structure comprising:

etching a trench around a release portion of a topside the bulk structure;

filling the trench with sacrificial material;

depositing and patterning a thin film layer on the bulk structure; and

removing the sacrificial layer.

12. The process of claim 11 further comprising planarizing the surface of the thin film layer.

13. The process of claim 11 further comprising etching a backside of the bulk structure to pre-release the bulk structure.

14. The process of claim 13 further comprising releasing the bulk structure.

15. The process of claim 11 wherein the bulk structure comprises silicon.

16. The process of claim 11 further comprising depositing a reflective layer on the release portion of the bulk structure.

17. The process of claim 11 wherein the thin film material is from the group comprising:

polysilicon, polyoxide, nitride, silicon nitride, silicon dioxide, or silicon oxynitride.

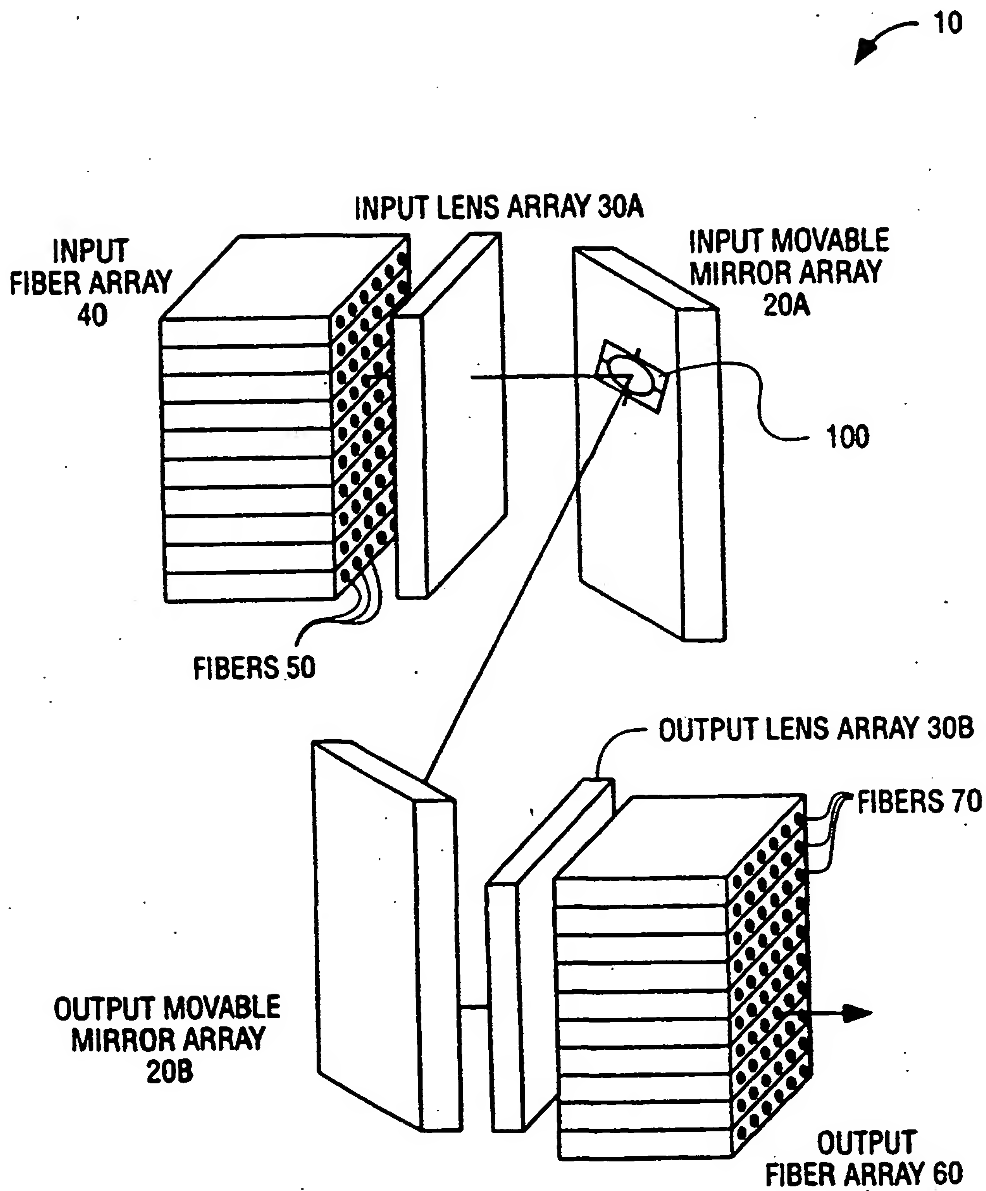
10
INPUT LENS ARRAY 30A
INPUT FIBER ARRAY 40
INPUT MOVABLE MIRROR ARRAY 20A
100
FIBERS 50
OUTPUT LENS ARRAY 30B
FIBERS 70
OUTPUT MOVABLE MIRROR ARRAY 20B
OUTPUT FIBER ARRAY 60

FIG. 1

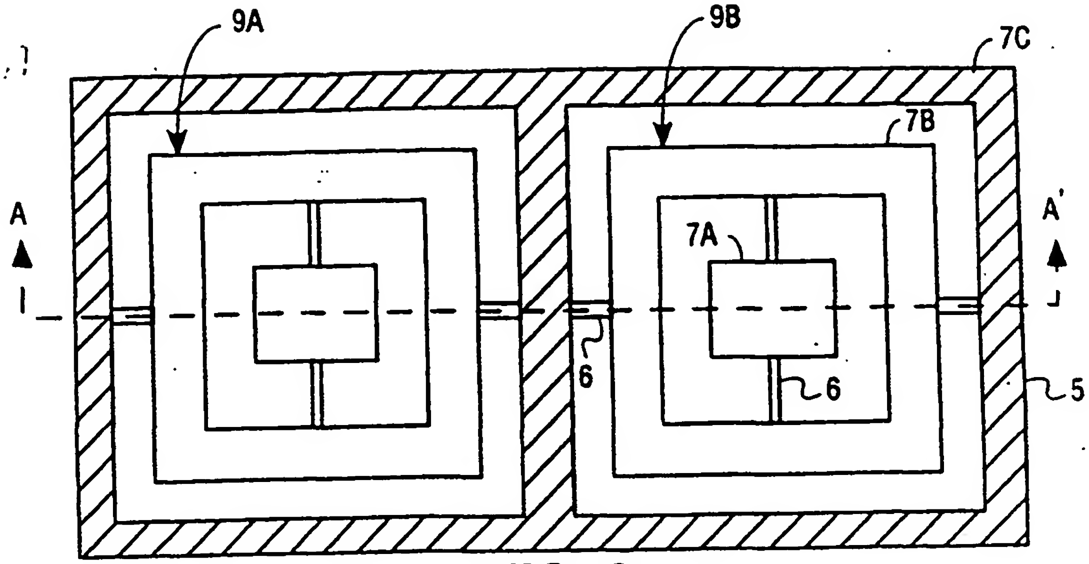

FIG. 2

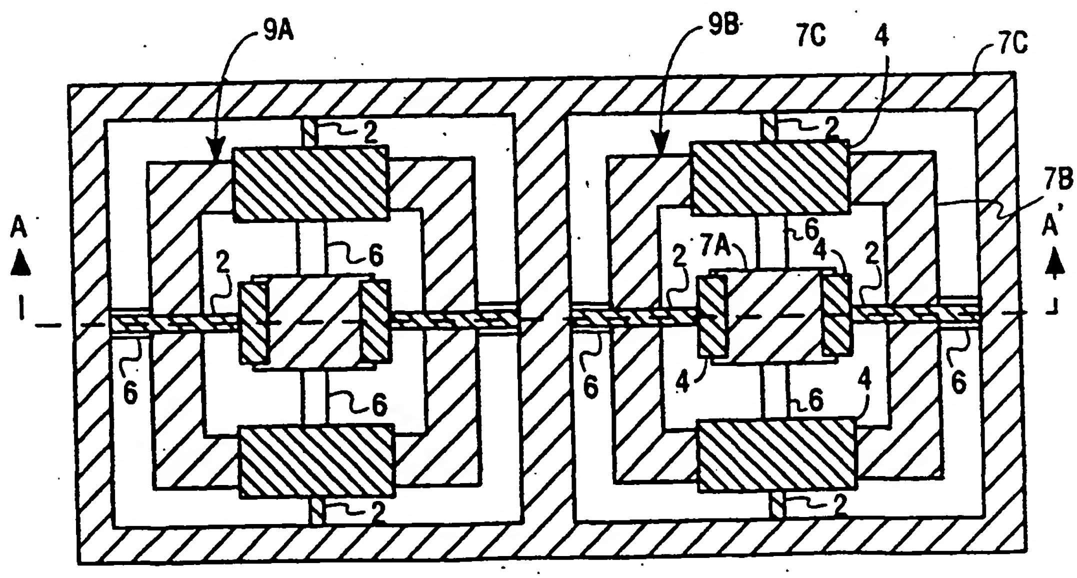

FIG. 3

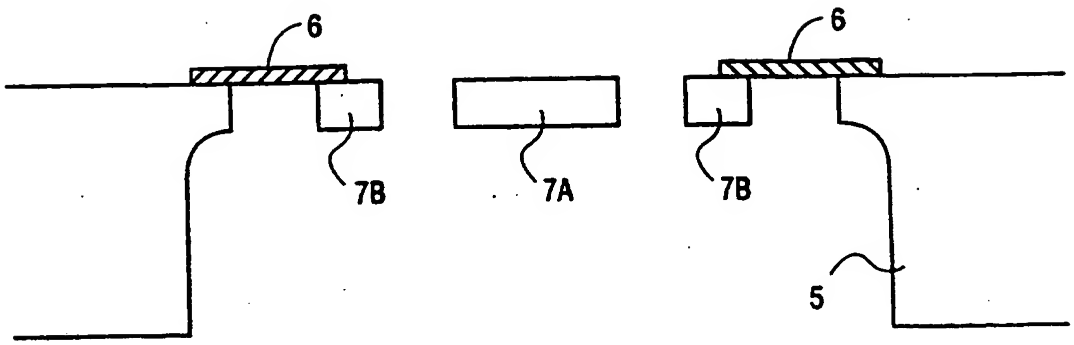

FIG. 4A

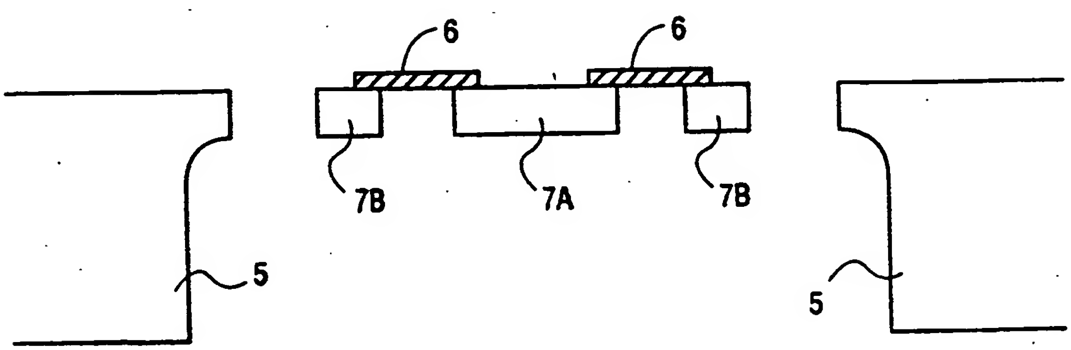

FIG. 4B

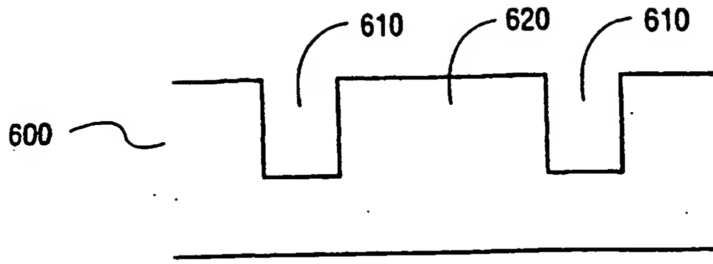

FIG. 5A

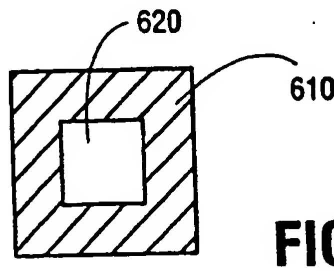

FIG. 5B

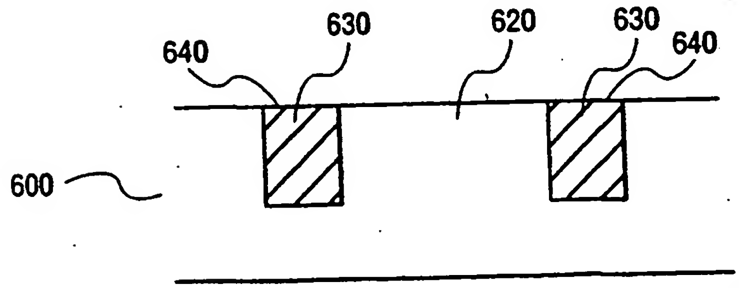

FIG. 5C

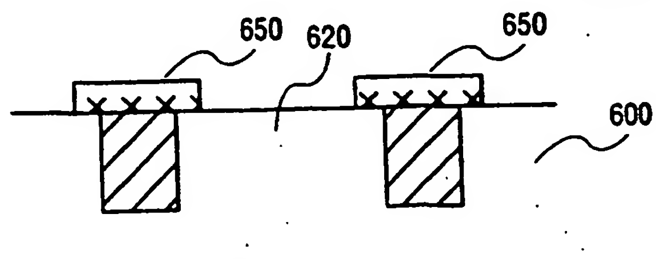

FIG. 5D

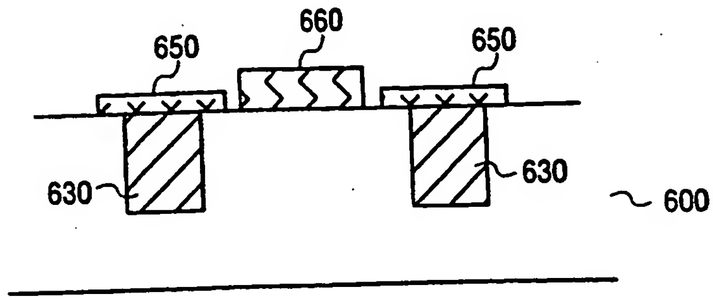

FIG. 5E

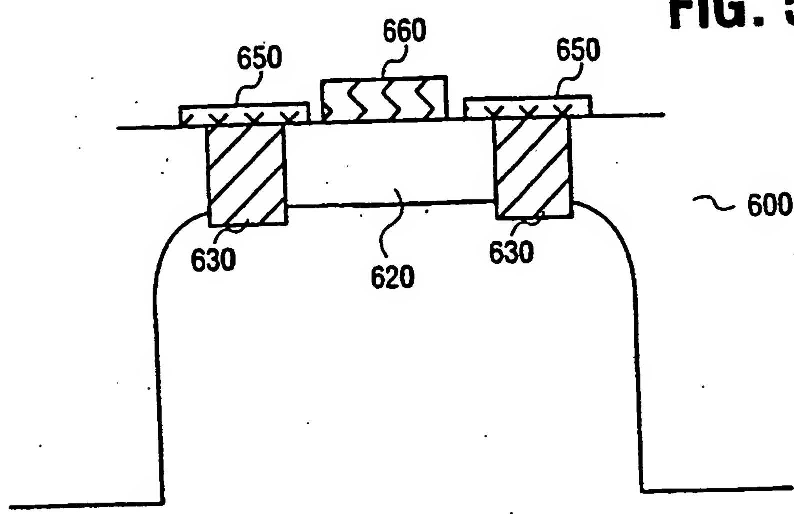

FIG. 5F

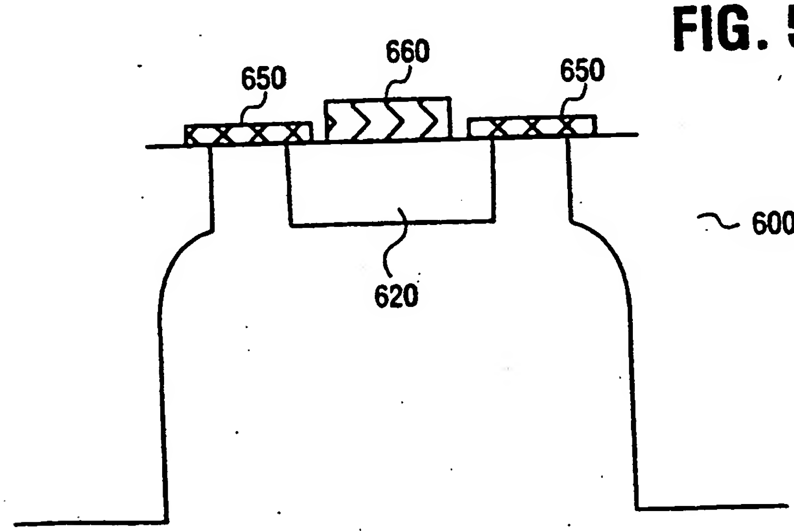

FIG. 5G